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SOCIO-ECONOMIC FACTORS AFFECTING DEMAND FOR MUNICIPAL COLLECTION OF HOUSEHOLD REFUSE

CHICAGO UNIVERSITY

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The influences of the socio-economic variables, race and income, on the demand for a municipally - provided collection service of household refuse were investigated. Marked seasonal variations in the effects of income and race alone and in combination, were noted. The results of the study may be interpreted to suggest that household refuse consists of two components. The basic solid waste component is independent of income and race and relatively constant throughout the year. The additional component varies seasonally and is highly sensitive to income and race except in midsummer when it appear to stem from consumption activities closely related to race.

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Decision Making and Solid Waste Disposal
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FOREWORD

Solutions to the Nation's solid waste problems have for the most part focused on developing the technological wherewithal for collecting and disposing of the wastes. Various means of disposal, including resource recovery have been developed; for example, sanitary landfill, incineration, pyrolysis, and energy conversion. Considerably less effort has been expended towards investigating the root causes of waste generation. There is now, however, a growing awareness that the real sources of waste are of an economic nature. It is the economic decisions involved in the daily production and consumption activities that cause the great quantities of wastes with which we are suddenly confronted.

This report investigates the potential relationship between several socio-economic characteristics and household refuse. Specifically, the study evaluates the influence of two socio-economic variables, income and race, on the demand for municipally-provided waste collection service. It is hoped that the results of this study will provide planners and policymakers with additional information for developing strategies to manage the increasing quantities of household refuse.

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Principal investigators for the study were Dr. John R. Sheaffer and Dr. George S. Tolley. Dr. Jack Meltzer served as Director of the Center during the time of the study. Many additional persons contributed to portions of the main report, including persons in private and public service and various officials of the City of Chicago who cooperated in providing the necessary information. Dr. John F. Foster of Battelle's Columbus Laboratories prepared this condensed version of the report and Oscar Albrecht of the Solid Waste Research Laboratory, National Environmental Research Center, Cincinnati, Ohio served as the EPA's project officer.

ABSTRACT

This study has investigated the relationship between several socio-economic characteristics and household refuse. In particular, the two socio-economic variables, income and race, appear to have significant effects on the demand for municipally-provided waste collection services. There is a marked seasonal variation in the comparative effects of income and race, alone or in combination. One interpretation of these effects, based on data from quantities of municipal waste collected in Chicago, is that solid waste consists of two components. The basic waste component is constant throughout the year and is independent of income and race. The additional component fluctuates greatly with the season, and is lower in the winter. It is very sensitive toward income and race, except in midsummer. Then it stems from different but unidentified consumption activities, which are independent of income, and are more popular with nonwhite than with white families.

The general conclusion of this study is that the demand for household refuse collection service in Chicago is a positive function of the income level and the fraction of nonwhites using the municipal service.

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SUMMARY AND CONCLUSIONS

There are indications as a result of this study that the amount of household refuse collected is highly sensitive and positively correlated to household incomes. The amount of waste collected is also influenced by the proportion of nonwhites in the neighborhood. The relative influence of these variables on the total household refuse collected, however, varies according to the season of the year. The overall weekly quantity also shows marked sensitivity to season of the year.

Data for the 50 political wards in Chicago were made available by the Bureau of Sanitation which collects about half of the solid wastes in the City. The municipal service is restricted to residential buildings containing no more than four dwelling units.

To adjust for those households not served by the municipal collection service, data for the regression analyses were weighted by the fraction of households actually served. Socio-economic data for household income level, household size, and percentage of nonwhites were obtained from the 1960 Census of Population tract data, and updated by use of more recent Metropolitan survey information. Income distributions by wards were derived and estimates made of the variance within wards.

The econometric analysis defined two alternative dependent variables: (1) the pounds of solid waste collected weekly per dwelling unit, and (2) the pounds of solid waste collected weekly per capita. The explanatory variables tested were median income level per household, the ratio of nonwhites to total population in each ward, the average household size, and the variance of the income distribution within the political wards. The analysis employed three functional forms: linear, semilog, and double logarithm.

The values for income elasticities showed a definite seasonal pattern. Low income elasticities were observed for certain weeks in summer and winter. There was also a marked seasonal pattern for the impact of race on the amount of household refuse collected. For example, in midsummer the fraction of nonwhites was very important in determining the quantity of waste collected. On the other hand, in midwinter the race factor

was irrelevant. During most of the year, income as well as race were essential in explaining the demand for the municipal waste collection service.

A possible interpretation of the overall results is that household refuse consists of two components: (1) a "basic" waste component that remains constant throughout the year, and is independent of household income and race, and (2) an "excess" waste component that is highly fluctuative, reflecting a seasonal pattern such that it is dependent upon either income, or race, or both at certain times of the year. The "excess" waste component is of minor importance during midwinter. It increases in spring, reaches a peak in early July, and levels off throughout the fall. The "excess" waste is positively related to both income and race, except in midsummer when the income explanatory variable is insignificant. Then certain consumption activities appear to be more directly related to the proportion of nonwhites in the population.

I. ECONOMICS OF WASTES

THE NEED FOR ECONOMIC ANALYSIS OF WASTES

Waste products have been overly neglected in economic analysis. The preoccupation has been with end products and with the assumption that all products are desired. Until recently, almost no recognition has been given to the truism that acts of production and consumption merely transform materials without essentially altering their amount.

If waste products could be disposed of without cost and if they had nothing to contribute to further production, they might legitimately be treated as if they had disappeared. However, rising incomes have contributed to more and more materials being transformed into wastes, so that increasing amounts of waste from high concentrations of people in urban areas have led to increasingly obvious costs associated with the wastes.

Costs associated with wastes are partly those for removal and disposal by burning or burying, and partly the loss of economic values from lack of reuse of waste materials. Another cost of extreme concern is environmental degradation, such as offensive smells, auto graveyards, or air pollution from incineration. Environmental cost is usually external to the causer. Wastes are disposed of in the air, in water and in solid form, leading to costs for treatment, or to various health and esthetic detriments which may cost no less by remaining untreated.

While economists have given sporadic attention to the more common forms of air and water pollution, at least since the time of Pigou, solid wastes have been mostly neglected. Aside from fuels which pass into gaseous state and some chemicals and residues put into liquids, materials as they move through production and consumption stages emerge for disposal in solid form. The solid wastes include by-products of manufacturing and distribution activities, as well as household garbage and trash left over after consumption activity.

A framework relating (1) demand, (2) supply, and (3) pricing or cost of institutional disposal can be applied, giving

emphasis to unique problems encountered for these wastes. There is a demand to get rid of materials, i.e., solid wastes, which is met through a supply of waste disposal services including collection and processing. Particularly, because of the public role in waste disposal, the price paid for the services may or may not equal the cost of the services at the level of services provided. Conceiving of the intersection of demand and supply curves at a price provides a benchmark needed particularly for evaluating waste collection services not left to the free market. Estimates are needed of effects of public financial arrangements affecting waste disposal. A comprehensive economic analysis of wastes can be organized using this three-part framework of demand, supply, and price.

Demand for Waste Collection Services

Lack of serious economic analysis of waste generation and disposal has been a chief contributor to inadequacies in understanding the requirements for policy making toward waste handling. The gains would be great from applying to wastes some of the sophistication in conceptualizing and quantifying demand that has been applied to commodities traditionally analyzed. A first and most obvious use of the results would be to obtain better estimates of growth to be expected in the amounts of waste materials to be handled in the future. A second use of the results would be to suggest the scope for policies aimed at influencing waste through price and other incentives placed on those generating the wastes. A third use would be to provide a basis for understanding the incidence of benefits and costs of various public actions that might be taken to affect wastes.

Supply of Waste Collection Services

Public discussion to date has proceeded from scare predictions about massive increases in waste generation to seeking a "technological quick-fix", without serious consideration of the needed supply of waste disposal services. As a minimum, cost analyses are needed in evaluating alternative methods to reclaim or dispose of waste, because each method represents a part of the total of waste disposal services. Very little information is available about costs of waste disposal, even for publicly-

sponsored development and pilot projects. Economic analysis can help provide a needed framework for obtaining and analyzing disposal cost data, which is needed in turn for a variety of analyses of the private and public behavior in supplying waste disposal services.

Pricing of Private and Institutional Services

Having considered demand and supply separately, one can visualize a price determination for waste disposal services at the quantity of services where the demand and supply schedules intersect. For much household waste collection, this way of visualizing the situation is accurate because private scavengers pick up the waste. There is then a market determination of price. For cities where there is municipal collection and operation of facilities, "price" becomes a euphemism for institutional arrangements for providing waste disposal services. As suggested earlier, regardless of the particular institutional arrangements, conceiving of the intersection of demand and supply at a price for waste disposal services provides a benchmark.

When services are provided by the private sector, demands and supplies can be analyzed by observing the private market transactions and the associated prices. The market institution may not exist for some goods and services, however. In such instances, the decisions to allocate resources for supplying the goods and services (public goods) are usually made through political institutions. The service level for collection of household refuse, for example, may be determined by ordinance or regulation. As a result of the public role, the price paid for the service may not equal the supply price. The incremental unit price may in effect be zero when financed by a general tax. Even so, the use of the demand and supply concept provides a framework for evaluating the resource allocation implications and the income distribution effects of a particular set of institutional arrangements.

CONCEPTUAL FRAMEWORK FOR THE ANALYSIS OF DEMAND AND SUPPLY

Effects of Income on Solid Waste Generation

One of several effects of income is that higher income implies greater consumption of goods and services, and this, in turn will be associated with greater amounts of waste products. The quantitative effect of income on wastes depends in part on the importance of materials relative to labor in the increased consumption. To the extent that the additional goods and services are produced through the use of human effort, the generation of additional waste will be reduced. High income elasticities of demand for health and other professional care, for entertainment and for services to be attached to goods, all of which are labor intensive, suggest that this dampening effect is significant. Nonetheless, it is doubtful that generation of waste materials exhibits a negative income elasticity. As a first approximation, one might estimate the increase in wastes associated with increased income as the waste-weighted sum of the income elasticities of demand for waste-generating goods and services.

Households with higher incomes are likely to choose goods which have a higher level of services embodied in them. Much of of this service will consist in having got rid of waste products, as particularly in the case of processed foods. There is then a tendency for the removing of waste products to be shifted from the household to the firms preparing products which will be sold to the households. At the same time, a change in form of waste is to be expected - from less garbage to more containers. Within the category of containers, shifts from fiber materials to plastic may be explainable on the basis of relative prices of the two kinds of goods. These may be affected by sources of supply in nature and by changing relative costs of the two types of materials.

Rising income also leads to rising demand for quality of goods. This has implications for disposal of longer-lived items such as clothing and durables. The quality of a long-lived item tends to decline with age. Therefore, there may be a tendency to get rid of goods at an early age, i.e., the average scrapping age may decline and act to increase the average volume of waste. Another factor affecting scrapping is upkeep, e.g.,

cleaning of clothes and repairing of automobiles. Upkeep is labor intensive, and almost surely real upkeep costs rise secularly as real wages rise. The cost of maintaining quality in a unit of a good of an existing age will therefore rise. To maintain a desirable quality, the consumer has incentives to scrap earlier and buy a new item. Any changes over time in the quality-age profile of a good may also be expected to affect scrapping. Unlike the demand for higher quality and the phenomenon of rising upkeep costs, both of which tend to reduce scrapping age, it is not clear whether future changes in the quality-age profile can be expected to increase or decrease scrapping. Accumulation of knowledge should contribute to the durability of units, e.g., we know how to build cars that will last longer than they used to, but this might be outweighed by such factors as rising labor costs of building for durability and by shifts to less durable alloys due to rising metals cost.

Rising income may also lead to increasing the amount of waste from shortlived goods. The quality of food consumption can be raised through less scrupulous efforts to eat every bite and by throwing away leftovers instead of using them for further meals. Such actions to increase quality of consumption contribute to greater amounts of waste. Within the household, if there is a positive income elasticity of demand for cleanliness, there will be demand for greater frequency of collection and perhaps on average a demand for greater amount to be taken away rather than to allow a higher level of accumulation on the household premises. High income may also increase waste by reducing tolerances for interference of waste disposal with leisure. There is an income elasticity of demand to be free of waste disposal activities within the home. To some extent this may be met by changing the form of wastes, as when garbage disposals are installed. In addition the rising value of leisure should increase the quantity of wastes because it will be less worthwhile to scavenge materials for household use, e.g., less string and boxes will be saved.

Effects of Pricing on Solid Waste Collection

Very little is known about the relationship between the price of pick-up and the amount of a household's wastes set out

for collection. The demand for collection service may be quite elastic at lower income levels, even at low prices. A slight rise in charge for collection might induce a considerable reduction in amount of materials to be picked up.* The alternative to the pick-up service, is, of course, self-disposal. The social desirability of self-disposal by various means needs to be evaluated in terms of the effect on the social costs for managing solid wastes.

The demand for service level, e.g., curb or backyard pick-up and number of times per week, is probably considerably more price elastic than demand for quantity to be picked up, because the savings in costs from a reduction in service level are probably substantial and can be offset by relatively little effort within the home.

Similar kinds of reasoning can be applied to constructing a framework for the consideration of supply. Because waste collection from households is highly labor intensive and because the profitability of scavenging decreases as the price of labor rises in a materials-abundant economy, the supply price for taking away waste products from the home is likely to rise with increasing income. The increasing value of labor probably far outweighs the increasing scarcity of materials resulting from demands on natural resources.

CONCEPTS FOR ECONOMIC ANALYSIS OF DISPOSAL STRATEGIES

External Costs Associated With Disposal Sites

External costs imposed on those within the area near waste disposal sites may include loss of neighborhood status, the presence of safety and health hazards, or decreases in esthetic appeal. Potentially affected parties always exist, and there is always a risk that they will be burdened with an extra cost. A

*The American Public Works Association has published two books on details of waste practices in many cities (Refuse Collection Practice, 1967 and Municipal Refuse Disposal, 1970). Information is included on charges for refuse pick-up and the amount of refuse per household.

variety of means are available for reducing risk or dealing with it in planning for control of waste disposal methods:

a. The use of certain technologies may be required to reduce external cost problems. Compaction or incineration are frequently suggested to reduce problems such as blowing paper, for example.

b. Verbal promises may be accepted that an operation will be sanitary. A company's reputation and/or the affected public's trust in official promises may be significant in determining how much risk is really involved.

c. Legal promises may be made that standards will be met. There is then a further risk that funds for litigation in the future will be necessary, a risk which a community may not wish to bear.

d. Recompense in the form of tax reductions, direct money payments to individuals or the community, and/or donation of the completed landfill to the community have been tried. Legal questions can conceivably arise in the case of money payments.

e. Other benefits may be made available including free dumping or construction of parks or recreational sites. In some cases, these later uses may provide more tax revenues.

f. Modification of present dumps or presently unusable land to sanitary landfill may be a reduction in present risks.

g. Isolation of the site through means of distance, building of berms, planting shrubbery, or placement of fences may be acceptable to the surrounding area.

Other aspects of dealing with risk may involve:

a. The proximity of the disposal site to other industry and its degree of segregation from residential areas.

b. Eventual termination of use of the disposal site. In the case of landfills, this can be weighed against the benefits which may be present after completion.

c. The degree of expertise in the community surrounding the landfill site and the degree of trust in the testimony of experts.

Environmental Tradeoffs

When any environmental issue is raised, a determination must be made regarding the tradeoffs involved in alternative solutions. There are some issues which deal with nuisances, while others clearly deal with potential hazards. It is important that priorities be recognized. The desirability of reducing the visibility of sites or increasing the distance between these sites and residences must not lead the public or public officials to believe that isolation is a simple solution. The fact that there may be less protest against an isolated landfill site or an incinerator must be weighed against the possibility that more important hazards of air or water pollution may exist at such sites. Community protest is so often present at potential disposal sites that there is no doubt a tendency to jump at the first unprotested one.

A clear distinction must be made between two strategies for recovery and reuse of waste when recovery is under consideration to reduce environmental effects. One form of recovery involves recycling or reclamation, which returns the waste to its original use and source. Included here are newspaper reuse and returnable bottles, in addition to various forms of scrapping. A second form of recovery involves reprocessing, whereby wastes are broken down into their basic elements and either used directly as products or indirectly in some other process. Pyrolysis, composting, or the use of sewage sludge are examples of reprocessing. An important difference between these two strategies (recycling and reprocessing) is their emphasis on separation. Recycling efforts involve more separation technologies and greater use of labor. More often the overall problem is finding a market for the recovered material or a viable system into which the products can be introduced for consumption.

Social Implications in Solid Waste Management

A high proportion of the solid wastes produced in the United States are still disposed of by means of open dumping, sanitary landfills, or incineration. Pressure to outlaw open dumping and open burning will increase. Therefore, sanitary landfills will be necessary in nearly every area of the United States.

Where laws have been established, municipalities have usually made heavy industrial zoning and special permits a prerequisite to landfill operations. Public hearings are typically required for these special permits and for zoning changes, and opposition at these hearings is frequently enormous. Public reactions are usually a result of disagreeable associations with dumps, so that understandably very few people wish to live next to open dumps. Although public officials and private operators frequently contend that their proposed sites will be sanitary landfills and that they will be well operated, there is always a risk that they will not be.

The general public's perceptions of the problems that will be present at sanitary landfills are formed through a variety of sources, such as the mass media, experience with disposal sites in individual areas, and information circulated by public agencies or private companies. The latter sources are undoubtedly the least pervasive and, especially in times of crisis, they are probably the least trusted. In contrast, the mass media present not only articles directly concerned with disposal problems, but perhaps more importantly they promulgate unfavorable perceptions developed over long periods of time. Literary and journalistic sources thus reflect and further develop an unfavorable image and antagonistic attitudes about disposal sites.

Costs of Alternative Disposal Strategies

The best cost information available for an alternative disposal of solid waste is that for incineration, largely because there have been many engineering consulting studies for cities contemplating building incinerators. Most of these are hypothetical cost studies, based on applying selected input prices to an assumed technology. Information is usually insufficient

to judge the realism of the assumptions. The results of studies are difficult to compare because of differing accounting procedures, e.g., some include administrative overhead as a variable cost and others do not.

Less information, but in a form generally similar to that for incinerators, is available for landfills. Private firms are understandably reluctant to reveal their costs, and it has been found difficult to obtain all the costs needed from public officials either. Practically no comparable costs information is available for any of the newer technologies that are receiving publicity, because they are not actually in use.

Thus, in the present state of knowledge, definitive comparisons of different methods of disposal are not possible. What can be done is to take stock of what is known and assign a range of costs to each major method, e.g., landfill, incinerator, rail haul, pyrolysis. In spite of the wide ranges, some feeling for orders of magnitude can be obtained. For instance, it appears that rather extreme conditions are required in order for incineration to be less expensive than the sanitary landfill method. Available cost data on the newer technologies suggest they are generally more costly than either incineration or landfill.

The broad range of costs which can be assigned to various disposal methods indicates areas that particularly need further cost work. Costs and optimum technology depend on local conditions such as population density, relative factor prices, and service level demanded. At present only generalizations can be made about the broad magnitudes of costs for alternative methods of disposal and how they vary with local conditions. However, these should be useful in guiding future data collection and cost analysis.

The purpose for economic analysis of disposal strategies is to develop formulas to aid public officials in deciding on methods of disposal with proper consideration of local conditions. At present, decisions appear to be based on little or no analysis or at best are based on quick studies using generally inadequate analysis. The following decisions could be analyzed: (a) how to decide on type of pickup truck and number of men per truck, particularly in view of local wage rates, (b) how to decide between building an incinerator or using the landfill method,

(c) how to decide whether a transfer station is economical in view of distance to ultimate disposal site, and (d) how to decide on landfill site giving attention to opening costs, operating costs, and present value of reclaimed land after completion of the fill.

II. DEMAND FOR WASTE COLLECTION SERVICES IN CHICAGO

CONCEPTUAL FRAMEWORK FOR THE ECONOMIC ANALYSIS OF SOLID WASTE

In the present day society, it is clear that more and more solid wastes are being produced, such that the disposal of an ever-increasing volume of wastes is a problem. To predict future development, it is not acceptable simply to extrapolate the past trend, because new trends may become predominant that could be detected by a careful and systematic analysis of available data. A simple extrapolation would also ignore specific information that is already available.

Solid wastes are not coming from nowhere. They are by-products of economic activities. The decisions of producers to make goods for the market as well as decisions of consumers to use goods include waste decisions that affect the generation of waste. To the producer, solid waste is often simply an output with a zero price, although if the need for disposal services is taken into consideration, it can lead to a significantly negative value for the waste.

To the private household, the waste decision is closely connected with the selection of the optimal commodity bundle. Thus, the producer's waste decision should be analyzed as part of his production plans, while the householder's waste decision must be understood as one component of his consumption plan.

One justification for developing methods for economic analysis of solid waste is that solid waste management is already very expensive when all external costs are taken into account, and it will become much more expensive in the future. If the consumer is to realize the true economic consequences of his consumption decisions, solid waste collection and disposal may have to be an incrementally priced service related to the amount of waste generated. The demand function for these services, based on the householder's waste decisions, becomes important in the formulation of sound policies and institutions to deal with the future volume of household solid wastes. The theory of consumer's choice tells us that there are interactions between

consumption plans of consumers and the inherent waste decisions of both producers and consumers. These interactions will, in the long run, affect the pattern of waste-generation and its distribution between producers and consumers, and thereby also affect the demand and pattern of waste disposal services.

The data were not available for analyzing directly the influence of the selected socio-economic variables on waste generating activities. Therefore, the procedure was to trace the relationship indirectly by relating quantity of household refuse collected to the selected variables. One could also not expect to detect long-term changes in consumption and refuse generating habits for the short interval of one and a half years available for the analysis. Any trends during this period would be overwhelmed by seasonal fluctuations. Nonseasonal variation would be within the waste distribution; i.e., contained in the variance of waste output between the cells of the weekly cross sectional data.

The approach adopted thus observes the sensitivity of a waste distribution with respect to seasonal variations of demand for the collection service. During the passage of a given year, the consumption patterns will exhibit seasonal fluctuations that are reflected in several ways. For one, the overall quantity of waste will change by season. Secondly, the degree to which wastes are explained by the variables for income, household size, and ethnic descent might also change. Moreover, the form of the relationship between the socio-economic variables and household refuse might be affected by the seasonality factor. Thus, the sensitivity of solid waste outputs with respect to the explanatory variables will not be stable but vary seasonally. An analysis of the way in which this happens will provide a deeper insight into the nature of the demand for waste collection services than would be possible from studying just one cross section.

The Chicago Data on Socio-Economic Characteristics and Waste Collections

This study is based on records of weekly collection of solid wastes from residential buildings with four dwelling units or less*, in Chicago's 50 political wards. The amounts of solid wastes were reported by the Bureau of Sanitation. Roughly

*Department of Air Pollution Control, 1966, p 11.

one-half of all solid wastes accruing in the City of Chicago are served by the municipal free collection service. The cross section study aggregates these data by areas within Chicago and relates them to socio-economic characteristics of households. Many data were examined and organized in this analysis, which includes the large number of individual loads of waste weighed during two years, and conversion of census tract data on socio-economic characteristics to a ward basis so as to be comparable to the load data. Adjustments also had to be made because not all data were available for the same year.

The Empirical Waste Distribution in Chicago

Figure 1 shows for the year of 1969 the seasonal fluctuations in the overall weekly output of solid wastes, measured in pounds per dwelling unit.* The sensitivity of the overall waste collection with respect to seasons is quite marked. Demand for waste collection services was low in the first 2 months of the year, at a rate of 40 to 45 pounds per week. It increased in April, reached a peak in early July and remained at a high level of 55 to 65 pounds from early September to late November, and fell to 45 pounds at Christmas.

For any given week, the average waste output in pounds per dwelling unit varied substantially among political wards. Table 1 shows waste yields in pounds per dwelling unit for the 50 wards of Chicago for selected weeks of 1968 and 1969. The median yields in Weeks 21, 32, and 50 were 57.1, 59.2, and 44.8 pounds in 1968 and 55.9, 61.8, 45.2 pounds in 1969, respectively. The ratio between highest and median yield** was roughly constant at a value between 1.23 and 1.42 (e.g., Week 50, 1968 and 1969). While this suggests that the waste distribution between wards simply expanded or shrank according to season, the relative positions that the various wards held within the distribution shifted dramatically over the year. Some wards kept a stable position within the waste distribution while others shifted

*Weeks Nos. 1, 13, 17 were not reported in our body of data.

**That is, the ratio of the yield of that ward which ranked first to the average yield of the two wards with Ranks 25 and 26. We preferred to use this ratio to that between highest and lowest yields because the extremely low and nearly constant yields in the 42nd ward would have distorted the ratio otherwise.

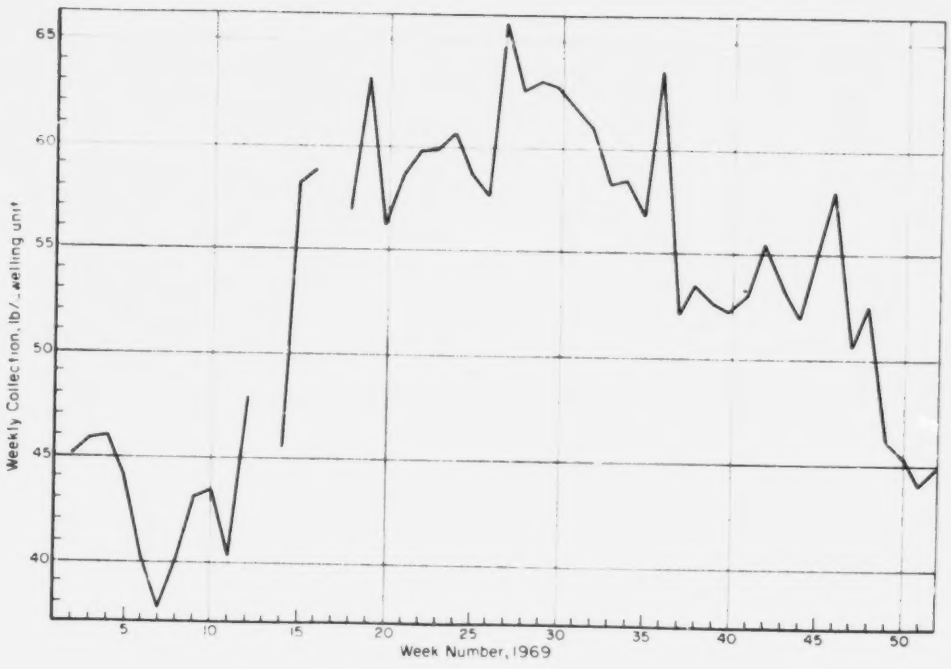

FIGURE 1. AVERAGE WEIGHT OF SOLID WASTE PER DWELLING UNIT

TABLE 1. WEEKLY COLLECTION OF SOLID WASTE IN POUNDS PER DWELLING UNIT, BY POLITICAL WARDS (CHICAGO, 1968 AND 1969)

Ward No.	Week No.:	21		32		50	
	Year:	1968	1969	1968	1969	1968	1969
1		49.8	45.1	52.4	53.3	41.1	39.7
2		43.2	51.6	62.7	50.9	36.5	29.2
3		81.6	83.5	80.7	82.8	63.7	52.6
4		33.2	37.3	36.4	41.4	26.5	25.1
5		60.9	57.8	60.6	50.6	46.7	40.6
6		46.4	50.6	55.6	46.5	33.0	34.6
7		46.2	51.9	46.0	50.8	36.3	40.7
8		57.3	66.9	59.9	64.0	43.3	50.3
9		53.5	57.5	47.5	53.4	37.2	41.1
10		60.8	73.2	65.4	71.7	43.9	49.4
11		46.9	47.0	46.6	46.2	47.2	42.4
12		48.9	51.8	51.1	50.4	41.9	38.3
13		62.9	66.8	64.1	67.4	49.3	50.7
14		52.9	57.0	53.7	50.2	44.5	45.0
15		60.2	59.7	64.1	56.5	45.6	43.6
16		52.7	62.4	69.1	66.2	45.3	48.3
17		57.8	65.5	68.0	77.0	42.2	50.1
18		68.6	75.0	77.7	76.6	55.6	54.7
19		76.4	75.3	83.5	70.1	45.7	51.4
20		50.3	73.6	60.9	70.5	45.5	47.1
21		62.5	66.0	67.8	66.2	44.2	49.2
22		48.2	54.7	53.3	52.2	38.2	41.9
23		75.1	79.4	89.9	78.5	53.3	53.4
24		50.6	62.0	63.7	65.3	47.8	41.3
25		47.6	55.2	57.5	60.0	44.8	43.2
26		41.1	45.5	50.6	47.3	39.6	37.6
27		57.2	48.5	54.2	50.9	43.3	42.9
28		56.9	60.2	62.0	65.5	48.6	43.9
29		51.1	51.9	64.5	62.8	43.0	43.6
30		61.2	60.6	59.3	66.9	50.3	49.7
31		42.5	40.3	48.9	48.9	40.9	41.3
32		34.6	36.7	38.5	40.5	30.1	31.4
33		40.0	44.3	41.3	44.3	36.2	35.0
34		58.6	64.2	64.6	64.3	54.9	51.7
35		54.7	53.4	50.8	55.6	43.4	45.3
36		66.8	62.6	64.2	61.4	56.3	53.8
37		61.2	62.3	63.2	66.1	51.0	51.5
38		72.5	65.9	62.9	69.0	44.8	47.5
39		66.3	67.0	64.1	68.2	47.4	47.9
40		65.7	63.5	57.3	63.5	53.5	48.4
41		63.5	66.9	62.1	67.2	44.0	47.6
42		21.9	24.3	23.2	24.8	23.5	24.1
43		45.4	52.4	46.2	52.8	44.7	44.7
44		44.7	47.1	47.8	51.4	42.0	43.6
45		67.7	69.8	70.6	73.2	52.5	55.0
46		48.9	51.6	55.1	53.4	42.2	44.9
47		58.9	56.6	59.1	63.2	47.9	51.4
48		63.6	61.2	58.8	64.9	51.5	45.9
49		60.6	62.5	58.6	64.8	54.4	55.7
50		64.6	60.1	57.5	58.2	48.8	51.5

markedly in rank. Still others maintained high (or low) ranks in one season of the year for each of the 2 years.

Procedures for Data Evaluation

To overcome the data limitations, it was decided to relate the seasonal sensitivity of the waste distribution by wards to selected explanatory variables. The data on seasonal sensitivity and the explanatory variables, income, race, or family size, have additional limitations. The solid waste data refer to only those families residing in structures served by the city with four or less dwelling units. The explanatory variables, however, characterize the total population of any given ward. Families residing in high-rise apartments may differ in characteristics from the rest of the population. The diversity could be especially great in wards adjoining Lake Michigan, which contain luxurious lakefront apartments (not municipally served) and also rather low-income households (with a probability of being served).

Another problem is the incompleteness of the data describing the explanatory variables. Ideally, one should have corresponding information on separate households, giving not only waste outputs, but also the corresponding levels of income, household size, and so on. Information is available only on nonhomogeneous large groups of households, with one average value for each explanatory variable, instead of values corresponding to the data on weekly waste collections in 1968 and 1969. The information dates back as far as 1960. Thus, these data must also be adjusted to reflect more closely the situation in 1968 and 1969.

The Use of Weighted Observations to Evaluate Incomplete Waste Collection Data

In order to adjust the incomplete data on waste collections for the total population in each ward, this analysis uses a weighting procedure. That is, if a high fraction of the population in a ward was served by the city, then the data on waste from that ward were entered into the regression analysis with a high weighting factor. Where the fraction was low, the observation was given a smaller weight. Our choice among several different weighting schemes was to use the squared fraction of households

municipally served. Squaring has the effect of accentuating wards for which the values of explanatory variables are highly representative.

The Fraction of Waste Collected by the Municipality

To estimate the total volume of household solid wastes for each ward from the partial collections reported in the municipal data, we used data provided by the Department of Air Pollution Control*, showing the distribution of commercial buildings, weighted by square feet of floor space, and of residential dwelling units in each square mile of the City. For residential units, it was noted whether or not they were served by municipal disposal. The absolute number of units served by municipal collection and disposal service in each ward is shown in Table 2. By superimposing the net of square miles on a map depicting the geographical location of political wards, we derived the fraction of total units served in each ward by assuming that overall refuses are distributed among geographical areas according to the number of dwelling units and the number of square feet occupied by commercial firms. This permitted an estimate of the ratio between municipal and private collections of household refuse in each ward, and therefrom the fraction of total refuse collected by the City. These estimates are presented in Table 2.

It will be noted that the municipal data are quite representative of the total volume of household wastes in some wards, where up to 97 percent of all household refuse were picked up by the City, while the data do not represent a large fraction of the total in others: only 23 percent of all household solid wastes were municipally collected in the 5th ward.

Income

The most important explanatory variable was likely to be income. The 1960 Census gives the number of households in 13 income brackets for each census tract. To obtain the corresponding distribution for wards, census tracts were superimposed on a map of political wards, and the tracts (or parts of them)

*The cooperation of Mr. Richard J. Seely from the Department of Air Pollution Control is gratefully acknowledged.

TABLE 2. MUNICIPAL COLLECTION OF SOLID WASTES, BY 50 POLITICAL WARDS OF THE CITY OF CHICAGO, 1968

Ward No.	Total Units Served	Fraction of Total Household Refuse Collected	Ward No.	Total Units Served	Fraction of Total Household Refuse Collected
1	19,869	0.661	26	22,207	0.657
2	7,342	0.414	27	13,087	0.593
3	7,050	0.348	28	14,062	0.674
4	9,291	0.241	29	17,577	0.663
5	3,793	0.230	30	14,315	0.806
6	17,758	0.654	31	18,902	0.791
7	13,679	0.632	32	25,904	0.762
8	22,125	0.817	33	22,155	0.852
9	22,379	0.953	34	17,298	0.815
10	22,666	0.936	35	18,962	0.854
11	22,358	0.683	36	21,705	0.943
12	22,336	0.943	37	13,550	0.743
13	26,164	0.957	38	21,215	0.956
14	17,363	0.850	39	15,335	0.845
15	18,185	0.919	40	14,248	0.772
16	18,495	0.870	41	23,896	0.973
17	14,775	0.652	42	11,788	0.336
18	20,680	0.908	43	12,831	0.564
19	21,899	0.963	44	12,856	0.566
20	10,119	0.461	45	20,945	0.940
21	28,837	0.955	46	10,422	0.487
22	19,962	0.848	47	15,811	0.670
23	22,472	0.976	48	3,537	0.285
24	11,067	0.546	49	6,720	0.397
25	23,543	0.736	50	15,562	0.702

were allocated to the corresponding wards. This yielded the number of households in the 13 income brackets for each of the 50 political wards in 1960. Table 3 shows the median income for each political ward.

The year 1960 was too distant from the year 1968/69 for which data on solid wastes by wards are available. It would not matter so much that the absolute income levels grew in the meantime, if the relative income differences between wards would remain about equal. However, changes in the City of Chicago were substantial during the sixties, and it was expected that the income structure between wards also changed significantly.

To identify these changes, estimates of the median family income in 1966 prepared by the Hospital Planning Council for Metropolitan Chicago were used. These figures refer to community areas (not wards). To derive the ward data needed for analysis, maps of community areas and political wards were superimposed, and the 75 community areas were allocated among the 50 wards of Chicago. Thus, for each ward it was decided which community areas fell within its borders and what the relative weights were. The median income (i.e., the geometric average of all incomes) for each ward was then compared by taking the weighted geometric mean of the median community area incomes assigned to each ward. To select the weight by which the ith community-area income entered the mean for jth ward's income, that part of the jth ward's geographical area was used which was covered by the ith community area. The estimates of the median 1966 ward incomes are presented in Table 3. In order to facilitate comparisons between 1960 and 1966, the rank of each ward with respect to its median income is listed for both 1960 and 1966.* The changes in rank of wards between 1960 and 1966 show that the Chicago income distribution had changed considerably. This reflects the fact that the economic structure within the Chicago area was indeed no longer the same as it had been in 1960.

Figure 2 shows that the proportion of residences served with municipal waste collection service has a marked positive relationship to income. It can be seen that high-income wards obtain a higher proportion of municipally provided waste collection service than do low-income wards. Since the municipal

*The ward median income estimates were adjusted for aggregation bias resulting from superimposing the 1966 community area figures.

TABLE 3. MEDIAN INCOMES AND RANKS OF INCOMES IN 50 POLITICAL WARDS OF CHICAGO, 1960 AND 1966

Ward No.	Median 1966 Income, $	Rank, 1966	Median 1960 Income, $	Rank, 1960
1	4,600	48	4,471	46
2	4,325	49	3,532	49
3	5,108	47	3,892	48
4	6,251	44	4,473	45
5	7,627	28	5,223	42
6	6,896	37	5,484	36
7	8,205	23	7,780	7
8	8,238	22	7,505	11
9	7,309	34	6,745	22
10	8,888	12	7,228	16
11	7,222	35	5,893	33
12	8,314	19	6,671	23
13	9,420	8	7,704	9
14	7,544	30	6,232	29
15	8,763	15	7,365	14
16	6,957	36	5,831	34
17	6,894	38	5,300	39
18	10,200	5	8,202	4
19	11,700	1	9,320	1
20	5,881	45	4,604	44
21	8,750	16	7,043	20
22	7,371	33	5,924	32
23	9,200	11	7,545	10
24	5,270	46	4,335	47
25	6,600	40	5,311	38
26	6,550	42	5,282	41
27	4,275	50	3,423	50
28	6,573	41	5,384	37
29	6,400	43	5,296	40
30	8,650	18	6,907	21
31	8,000	26	6,364	28
32	7,490	31	5,820	35
33	8,280	20	6,609	25
34	8,050	25	6,502	26
35	8,750	17	7,173	18
36	8,800	14	7,066	19
37	9,230	9	7,432	13
38	9,600	7	7,829	5
39	9,829	6	7,776	8
40	9,200	10	7,327	15
41	11,500	2	8,707	2
42	6,890	39	4,806	43
43	7,460	32	6,075	30
44	7,600	29	6,661	24
45	10,375	4	7,821	6
46	7,840	27	6,478	27
47	8,849	13	7,215	17
48	8,090	24	5,965	31
49	8,240	21	7,436	12
50	10,450	3	8,369	3

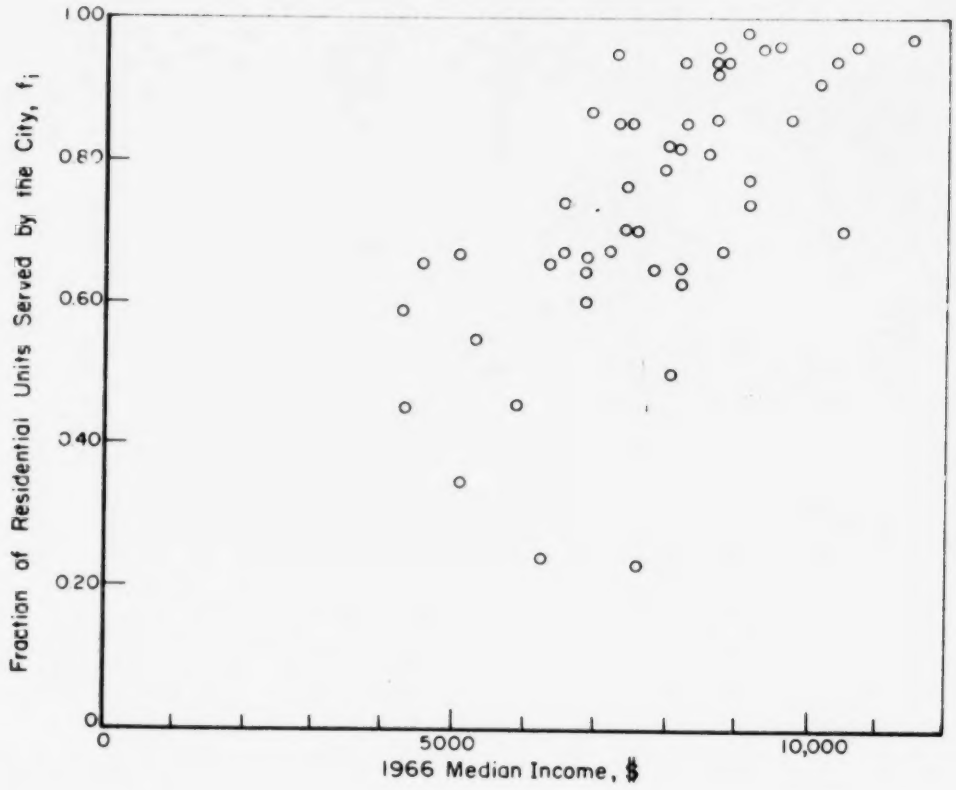

FIGURE 2: RELATION BETWEEN MEDIAN WARD INCOME AND THE FRACTION OF RESIDENTIAL DWELLING UNITS SERVED BY CHICAGO MUNICIPAL WASTE COLLECTION SERVICE

collection in Chicago is financed from the general tax fund, it could mean that the higher income households indirectly receive a subsidy. Thus institutional arrangements, such as financing solid waste collection and disposal services in a manner not directly related to the service demanded, may have unforeseen side-effects that should be considered in planning solid waste management.

Population, Household Size, and Fraction of Nonwhites

Besides income, the fraction of nonwhites was considered a potentially important variable, because consumption habits may well differ for nonwhite and white families with equal incomes. In addition, household size might be a relevant variable. On the one hand, large households are likely to produce more pounds of waste per household than small ones do, simply because more persons live in them. On the other hand, on a per capita basis, consumption patterns are likely to be influenced by household size.

The population by wards in 1960 was available from a study of the Department of Development and Planning. To estimate the 1960 average household size by wards, the corresponding information from the 1960 Census was used. A map of the 1960 Census tracts was superimposed on a map of political wards, and tracts (or parts of tracts) were allocated to corresponding wards.

Again, more recent information on population by political wards was needed, so population estimates for 1968 by wards made by the Department of Development and Planning (1969) were used. These figures are based on the 1960 Census data, to which rates of change in the number of registered voters were applied. As the report itself states, this method is not entirely satisfactory: "In wards where long established families moved out and were replaced by recent out-of-state immigrants, the voter-registration figures would drop without a proportionate decrease in total population". Therefore, computations of our own, based on the 1966 figures for community areas as presented by the Hospital Planning Council for Metropolitan Chicago, were transformed into ward data by means of the procedure described above. The study of the Hospital Planning Council was also used to derive estimates on the ratio between the nonwhite and white population by wards in 1966.

Table 4 lists the 1960 and 1968 population data by the Department of Development and Planning, the 1966 data derived from the Hospital Planning Council figures, the ratio of nonwhite to total population adapted from the same source, and the 1960 average household size. These data were employed in the analysis which follows.

ANALYSIS OF THE DATA

Two alternative dependent variables were used in the econometric analysis: D_i, the pounds of solid waste generated weekly per household (one dwelling unit) in the ith ward; and C_i, the pounds of solid wastes generated weekly per capita. Explanatory variables were the median income of the ith ward, Y_i; the ratio of nonwhite to total population, N_i; the average household size, S_i (used only when D_i is the dependent variable); and the variance of the income distribution, V_i.

Three functional forms of equations were used:* a linear equation relating dependent and independent variables; a semi-log relationship (natural logarithms are taken of the explanatory variables); and a double-log relationship (natural logarithms are taken of both the dependent and the explanatory variables).

Implications of Alternative Equations

To see what is implied by each form of equation, consider a two-variable model describing pounds of wastes per dwelling unit, D, as a function of the median income, Y. Disregarding the disturbance term, the linear equation is then:

$$D = \alpha + \beta Y \tag{1}$$

$$\frac{dD}{dY} \cdot \frac{Y}{D} = \beta \frac{Y}{D} = \beta \frac{Y}{\alpha + \beta Y} = \frac{\beta}{\frac{\alpha}{Y} + \beta} \quad . \tag{2}$$

*For a brief discussion and further reference, see Johnston Econometric Methods (1963), pp 44-49.

TABLE 4. POPULATION VARIABLES BY WARDS IN 1960, 1966, AND 1968

Ward No.	Total Population 1960[a]	Total Population 1966[b]	Total Population 1968[a]	Ratio Nonwhite to Total Population 1966[b]	Average Household Size, 1960[c]
1	79,822	91,015	80,000	0.35	3.26
2	75,197	74,046	86,000	0.90	3.49
3	65,341	69,935	49,000	0.99	3.13
4	74,186	82,428	65,000	0.89	2.95
5	78,766	87,997	83,000	0.68	2.70
6	75,709	67,359	68,000	0.92	3.23
7	75,887	82,503	76,000	0.32	2.60
8	79,308	87,316	90,000	0.39	3.09
9	76,508	69,811	84,000	0.22	3.41
10	77,885	78,173	87,000	0.03	2.54
11	65,257	70,138	61,000	0.06	3.39
12	60,076	62,691	61,000	0.01	3.19
13	80,231	94,491	91,000	0.06	3.30
14	63,858	40,403	58,000	0.12	3.38
15	61,696	46,602	63,000	0.04	3.02
16	66,060	55,593	64,000	0.57	3.53
17	72,063	78,882	74,000	0.83	3.62
18	79,215	71,493	87,000	0.20	3.39
19	79,635	79,528	87,000	0.14	3.47
20	74,937	71,001	66,000	0.95	3.09
21	80,909	101,750	103,000	0.40	3.55
22	62,224	48,147	54,000	0.28	3.32
23	77,966	91,482	92,000	0.04	3.57
24	70,824	48,861	55,000	0.95	4.40
25	79,260	88,069	81,000	0.50	3.80
26	68,635	65,059	58,000	0.02	3.24
27	70,919	76,801	59,000	0.67	3.24
28	59,781	73,233	59,000	0.44	3.29
29	71,086	68,152	64,000	0.88	3.79
30	61,455	57,375	55,000	0.11	3.09
31	61,599	53,013	54,000	0.03	3.15
32	64,349	54,071	57,000	0.02	3.15
33	69,664	71,383	64,000	0.01	2.91
34	66,677	57,529	60,000	0.01	2.94
35	63,682	47,879	63,000	0.00	2.88
36	68,578	77,072	70,000	0.01	3.00
37	61,712	47,208	58,000	0.01	2.76
38	71,142	76,353	80,000	0.00	3.16
39	61,116	74,643	62,000	0.02	3.01
40	72,139	50,427	68,000	0.02	3.03
41	68,259	75,576	78,000	0.06	3.34
42	60,772	62,642	68,000	0.38	3.24
43	65,179	73,502	64,000	0.14	2.48
44	76,759	--	81,000	0.08	2.36
45	72,839	--	78,000	0.00	3.08
46	74,319	--	73,000	0.03	2.40
47	79,631	68,684	76,000	0.02	2.69
48	71,968	75,790	77,000	0.05	2.12
49	79,363	75,828	94,000	0.02	2.41
50	79,153	84,357	88,000	0.00	2.96

(a) Source: Department of Development and Planning (1969).
(b) Adapted from Hospital Planning Council (1966).
(c) Adapted from 1960 census data.

Thus, the income elasticity, $\frac{dD}{dY} \cdot \frac{Y}{D}$, is positive when α and β are both positive; it is less than unity but approaches unity as Y increases. If Y were to increase exponentially with rate g in a time series context, then the income elasticity would follow a logistic curve:

$$\left(\frac{dD}{dY} \cdot \frac{Y}{D}\right)_t = \frac{1}{1 + \frac{\alpha}{\beta} Y_o^{-1} e^{-gt}} \tag{3}$$

where Y_o is the income at time zero.

If the linear equation works best (because R^2, the coefficient of determination, is highest) this implies that the income elasticity is less for low-income households than it is for well-to-do- households. It is, however, always less than unity for finite incomes.

The semilog form is

$$D = \alpha + \beta \log Y \tag{4}$$

$$\frac{dD}{dY} \cdot \frac{Y}{D} = \frac{\beta}{D} = \frac{\beta}{\alpha + \beta \log Y} = \frac{1}{\frac{\alpha}{\beta} + \log Y} \quad . \tag{5}$$

The income elasticity is thus positive if both α and β are positive. In this case, it is not necessarily less than unity but decreases as D increases, and approaches zero as D goes to infinity. As income increases, the same is true. If the semilog form works best, the income elasticity is higher for low-income households than it is for well-to-do families; instead of approaching unity as in the linear equation, it approaches zero as income rises.

The double-log equation is:

$$\log D = \alpha + \beta \log Y \tag{6}$$

$$D = e^{\alpha} Y^{\beta} \tag{7}$$

$$\frac{dD}{dY} \cdot \frac{Y}{D} = \frac{e^{\alpha} \beta Y^{\beta - 1}}{D} Y = \frac{e^{\alpha} \beta Y^{\beta}}{e^{\alpha} Y^{\beta}} = \beta \quad . \tag{8}$$

The income elasticity is thus equal to 1, and constant as income increases. If the double-log equation works best in empirical analysis, the same income elasticity applies to all households regardless of the level of their actual income.

The Effect of Weighting Regressions

To determine to what extent the weighting procedures used to adjust for incomplete waste collection data affected regression results, a set of regressions was carried out using (a) unweighted, (b) weighted by the fraction of residential dwelling units municipally served, f_i, and (c) weighted by $(f_i)^2$.

It turned out that $(f_i)^2$ was uniformly best by the criterion that R^2, the coefficient of determination, showed highest values. Therefore in the rest of this section, only the results weighted by $(f_i)^2$ will be discussed.

The Waste-Income Relationship

Household wastes in pounds per dwelling unit, D_i, correlates best with the explanatory variable Y_i by the linear equation. On the other hand, C_i (the waste per capita) correlates best by the double-log equation.[1] Thus, the income elasticity of solid waste collection by households is less for low income wards, while the income elasticity per capita appears to be constant at all income levels. However, the linear household equation shows a higher correlation of D_i with median income Y_i than the double-log per capita equation shows for log C_i with log Y_i.

The empirical income-waste relationships were further analyzed for sixteen selected weeks for both dependent variables, D_i and C_i, as shown in Table 5. In thirteen of the sixteen weeks the linear household specification, $f(D_i, Y_i)$, clearly dominates the logarithmic per capita equation, $f(\log C_i, \log Y_i)$. The three exceptions are: Weeks 32 (early August) in both years, and Week 7 (mid-February) in 1969.

[1] The semilog form is dominated in most cases by either the linear or the double log form.

TABLE 5. PARAMETERS OF THREE FUNCTIONAL FORMS OF EQUATIONS RELATING INCOME, Y_i, AND REFUSE COLLECTIONS, D_i AND C_i

Week No.	Name of Dependent Variable	$\hat{\alpha}_Y$	$\hat{\rho}_Y$	Name of Explanatory Variable	R^2
21/1968*	D_i	17.04 (5.82)	.00482 (.00067)	Y_i	.5213
	$\log C_i$	-3.390 (1.034)	.6977 (.1143)	$\log Y_i$	.4369
	$\log D_i$	1.748 (.977)	.6414 (.1080)	$\log Y_i$	.4237
24/1968*	D_i	19.11 (6.01)	.00451 (.00069)	Y_i	.4731
	$\log C_i$	-3.170 (1.124)	.6723 (.1242)	$\log Y_i$	.3789
	$\log D_i$	-1.527 (1.032)	.6159 (.1140)	$\log Y_i$	.3780
32/1968*	D_i	44.12 (6.88)	.00188 (.00079)	Y_i	.1062
	$\log C_i$	.322 (1.015	.2911 (.1123)	$\log Y_i$	.1229
	$\log D_i$	1.964 (1.051)	.2343 (.1162)	$\log Y_i$	.0784
36/1968*	D_i	31.41 (6.15)	.00388 (.00070)	Y_i	.3881
	$\log C_i$	-1.688 (.952)	.5213 (.1052)	$\log Y_i$	.3383
	$\log D_i$	-.045 (.898)	.4649 (.0993)	$\log Y_i$	.3134
37/1968*	D_i	19.57 (4.03)	.00197 (.00046)	Y_i	.2756
	$\log C_i$	-1.810 (1.126)	.4712 (.1245)	$\log Y_i$	.2298
	$\log D_i$	-.167 (1.014)	.4149 (.1121)	$\log Y_i$	.2219

TABLE 5. (Cont.)

Week No.	Name of Dependent Variable	$\hat{\alpha}_Y$	$\hat{\rho}_Y$	Name of Explanatory Variable	R^2
43/1968*	D_i	17.89 (5.50)	.00459 (.00063)	Y_i	.5259
	$\log C_i$	-3.681 (1.098)	.7278 (.1214)	$\log Y_i$	.4281
	$\log D_i$	-2.038 (.874)	.6715 (.0966)	$\log Y_i$	.5017
50/1968*	D_i	33.05 (4.67)	.00150 (.00053)	Y_i	1417
	$\log C_i$	-.359 (1.165)	.3367 (.1288)	$\log Y_i$	.1246
	$\log D_i$	1.283 (.884)	.2804 (.0977)	$\log Y_i$	.1464
7/1969	$\log C_i$	-.879 (1.096)	.376 (.121)	$\log Y_i$	.1674
	$\log D_i$	.763 (.811)	.320 (.090)	$\log Y_i$	.2100
19/1969	D_i	35.98 (7.15)	.00352 (.00082)	Y_i	.2792
	$\log C_i$	-1.312 (1.058)	.4822 (.1170)	$\log Y_i$	.2614
	$\log D_i$	.330 (1.014)	.4259 (.1121)	$\log Y_i$	.2312
21/1969	D_i	31.94 (6.50)	.0034 (.0007)	Y_i	.3068
	$\log C_i$	-1.40 (1.06)	.483 (.117)	$\log Y_i$	.2613
	$\log D_i$	.200 (.988)	.4318 (.1092)	$\log Y_i$	.2458
24/1969*	D_i	29.67 (6.81)	.00398 (.00078)	Y_i	.3519
	$\log C_i$	-1.89 (1.02)	.542 (.113)	$\log Y_i$	.3222
	$\log D_i$	-.25 (1.01)	.485 (.111)	$\log Y_i$	.2834

TABLE 5. (Cont.)

Week No.	Name of Dependent Variable	$\hat{\alpha}_Y$	$\hat{\beta}_Y$	Name of Explanatory Variable	R^2
32/1969	D_i	36.71 (6.95)	.00295 (.00080)	Y_i	.2238
	log C_i	-.93 (1.06)	.432 (.117)	log Y_i	.2219
	log D_i	.72 (1.02)	.376 (.113)	log Y_i	.1873
36/1969	D_i	29.56 (6.53)	.00436 (.00075)	Y_i	.4150
	log C_i	-2.156 (1.022)	.5768 (.1130)	log Y_i	.3516
	log D_i	-.513 (.936)	.5204 (.1034)	log Y_i	.3453
37/1969	D_i	25.05 (6.15)	.00340 (.00070)	Y_i	.3279
	log C_i	-1.940 (1.116)	.5293 (.1234)	log Y_i	.2770
	log D_i	-.297 (1.041)	.4730 (.1151)	log Y_i	.2603
46/1969	D_i	3.62 (5.80)	.00680 (.00066)	Y_i	.6863
	log C_i	-5.109 (1.004)	.9840 (.1110)	log Y_i	.5745
	log D_i	-3.467 (.923)	.3377 (.1020)	log Y_i	.5841
50/1969	D_i	-121.24 (33.75)	18.61 (3.73)	log Y_i	.3412
	log C_i	-1.714 (1.103)	.4889 (.1219)	log Y_i	.2509
	log D_i	-.071 (.797)	.433 (.088)	log Y_i	.3345

Semilog specification not tested this week.

There is a difference between the exceptional weeks in summer and in winter. In August, the linear equation, $f(D_i, Y_i)$, performs relatively well on a per household basis. In February, the household equation in logarithmic form performs better than the logarithmic per capita equation, that is, $R^2_{\log D} > R^2_{\log C}$.

The values which the income elasticity assumes follow a seasonal pattern. Figure 3a shows, on a per capita basis, the sixteen computed elasticities. Obviously the pattern observed in 1968 repeated itself in 1969. In both years, there is a low in Week 32. One might attribute this to vacations. However, the volume of solid wastes itself was not affected but remained quite high as already illustrated in Figure 1. The other income elasticity lows, occurring in winter (mid-December and mid-February), coincide with a very low absolute waste volume. Thus, the low income elasticities observed in August must have quite different causes from those occurring in winter. In Figure 3b the corresponding R^2 values are plotted against time. They follow the same pattern as the income elasticities. Thus, we cannot hope to explain much of the observed patterns by income variation.

The dominance of the logarithmic per capita model in August (clearly dominant in 1968 and nearly so in 1969) suggests that the total volume of solid wastes must be composed differently in that month than in June or September (i.e., in Weeks 24 and 36). There may be a high waste component resulting from consumption activities insensitive with respect to income, and performed on a per capita basis. The consumption goods may be soft drinks, beer, or fruits and vegetables. In winter, on the other hand, the lower volume generated may stem from a consumption activity which is also not very sensitive with respect to income, but is performed on a household basis (heating, for instance).

An alternative hypothesis would be this: there may be a "basic" volume of solid wastes which is invariably generated throughout the year on a household basis, and which is not very sensitive towards income (i.e., the income elasticity is constant and low for all income levels). In winter, a high proportion of all wastes is recruited from this hypothetical waste type. As the year goes on, wastes of a different type are generated in addition to the "basic" type. They also tend to occur on a per household rather than a per capita basis. These wastes, however, are quite sensitive to income, the more so the higher the income (i.e., the linear equation). The only exception is in

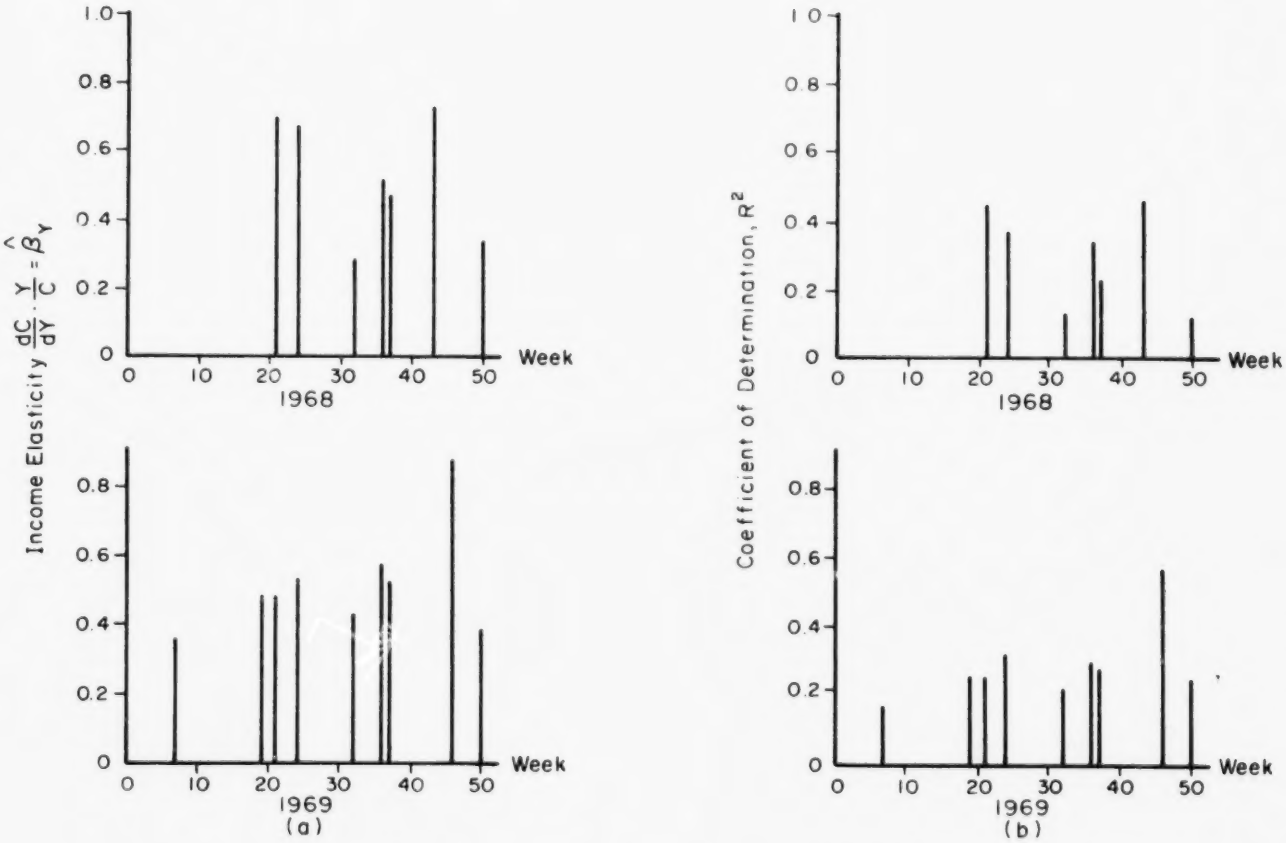

FIGURE 3 . SEASONAL VARIATIONS OF INCOME ELASTICITY AND COEFFICIENT OF DETERMINATION

midsummer when the "excess" waste is as insensitive with respect to income as the "basic" type, and is yielded on a per capita basis.

The Variance of the Income Distribution

The variance of the income distribution, taken as a single explanatory variable, is significant in most cases. In Week 43, 1968 (ending October 26), the income – waste relation is:

$$D_i = 17.89 + .00459\ Y_i + e_i \qquad R^2 = .5259 \qquad (9)$$
$$(5.50)\ (.00063) \qquad F = 53.25$$

The variance V_i alone yields:

$$D_i = 101.21 - 79.78\ V_i + e_i \qquad R^2 = .4480 \qquad (10)$$
$$(7.10)\ (12.78) \qquad F = 38.5$$

Both variables taken together result in:

$$D_i = 51.99 + .00318\ Y_i - 39.98\ V_i + e_i \qquad R^2 = .5886 \qquad (11)$$
$$(13.15)\ (.00079)\ \ (14.93) \qquad F = 33.63$$

Thus, the more inequalities of incomes exist in a ward, the less wastes are generated. Equation (11) indicates that households in the lower tail of the income distribution produce less wastes than would be expected from Equation (9). This is not surprising because it had been determined that the lognormal distribution of income with median income e^{μ} and variance σ^2 overestimated the income of the lowest income brackets. The highest values of σ^2 place more households erroneously in the lowest groups relative to the total.

In most weeks, the variance, V_i, becomes insignificant as soon as income itself is added. As a typical example, take Week 21 in 1968:

$$D_i = 17.04 + .00482\ Y_i + e_i \qquad R^2 = .5213 \qquad (12)$$
$$(5.82)\ (.00067) \qquad F = 52.26$$

$$D_i = 93.67 - 64.07\ V_i + e_i \qquad R^2 = .2602 \qquad (13)$$
$$(8.66)\ (15.60) \qquad F = 16.88$$

$$D_i = 22.80 + .00458\ Y_i - 6.75\ V_i + e_i \qquad R^2 = .5229 \qquad (14)$$
$$\quad (15.60)\ (.00090)\quad (16.95) \qquad F = 25.75$$

Household Size

Household size could be an important factor to explain the volume of wastes on a dwelling unit basis, D_i, because one would expect more solid wastes per household from large families. This expected relationship, however, was observed only in Week 32 in both years.

Week 32, 1968

$$D_i = 44.12 + .00188\ Y_i + e_i \qquad R^2 = .1062 \qquad (15)$$
$$\quad (6.88)\ (.00079) \qquad F = 5.70$$

$$D_i = 31.11 + 9.33\ S_i + e_i \qquad R^2 = .1644 \qquad (16)$$
$$\quad (9.57)\ (3.04) \qquad F = 9.44$$

$$D_i = 12.10 + .00203\ Y_i + 9.82\ S_i + e_i \qquad R^2 = .2877 \qquad (17)$$
$$\quad (11.14)\ (.00071)\quad (2.84) \qquad F \quad 9.44$$

Week 32, 1969

$$D_i = 36.71 + .00295\ Y_i + e_i \qquad R^2 = .2238 \qquad (18)$$
$$\quad (6.95)\ (.00080) \qquad F = 18.84$$

$$D_i = 38.16 + 7.67\ S_i + e_i \qquad R^2 = .0946 \qquad (19)$$
$$\quad (10.80)\ (3.42) \qquad F = 5.02$$

$$D_i = 9.26 + .00309\ Y_i + 8.42\ S_i + e_i \qquad R^2 = .3373 \qquad (20)$$
$$\quad (11.65)\ (.00074)\quad (2.97) \qquad F = 11.96$$

In the summer week of 1968, household size alone performs better than income; in 1969, the opposite is true. In both weeks, however, the combination of household size and income as explanatory variables is better. This supports the earlier hypothesis that in midsummer a high fraction of the total waste yield stems from a consumption activity which is not very sensitive toward income, and is performed on a per capita basis.

It has been inferred that the low income elasticity in winter (Figure 3, Week 50, 1968, and Week 7, 1969) and the corresponding low waste collection is related to households rather than individuals (Table 5). This is supported by the insignificance of household size in winter. For example, take the winter Week 50, 1968:

$$D_i = 33.05 + .00150\ Y_i + e_i \qquad R^2 = .1417 \qquad (21)$$
$$(4.67)\ (.00053) \qquad F = 7.927$$

$$D_i = 43.80 + .699\ S_i + e_i \qquad R^2 = .0019 \qquad (22)$$
$$(7.24)\ (2.297) \qquad F = .093$$

$$D_i = 29.57 + .00152\ Y_i + 1.067\ S_i + e_i \qquad R^2 = .1462 \qquad (23)$$
$$(8.44)\ (.00054) \quad (2.151) \qquad F = 4.024$$

There was one unexpected observation. When income elasticity and total waste volume are both high, the corresponding consumption activity resulting in waste is performed on a household rather than per capita basis. As a typical example, take Week 43, 1968. This is illustrated by the low value of R^2 in Equation (25) when household size is used as the single explanatory variable.

$$D_i = 17.89 + .00459\ Y_i + e_i \qquad R^2 = .5259 \qquad (24)$$
$$(5.50)\ (.00063) \qquad F = 53.25$$

$$D_i = 53.61 + 1.21\ S_i + e_i \qquad R^2 = .0023 \qquad (25)$$
$$(11.47)\ (3.64) \qquad F = .110$$

$$D_i = 10.30 + .00462\ Y_i + 2.33\ S_i \qquad R^2 = .5344 \qquad (26)$$
$$(9.88)\ (.00063) \quad (2.52) \qquad F = 29.97$$

Race

Correlation of the fraction of nonwhites, N_i, with waste per capita, C_i, is better than with the household unit D_i. Thus, the higher the fraction of nonwhites in a ward, the more wastes stem from consumption activities performed on a per capita rather than a household basis.

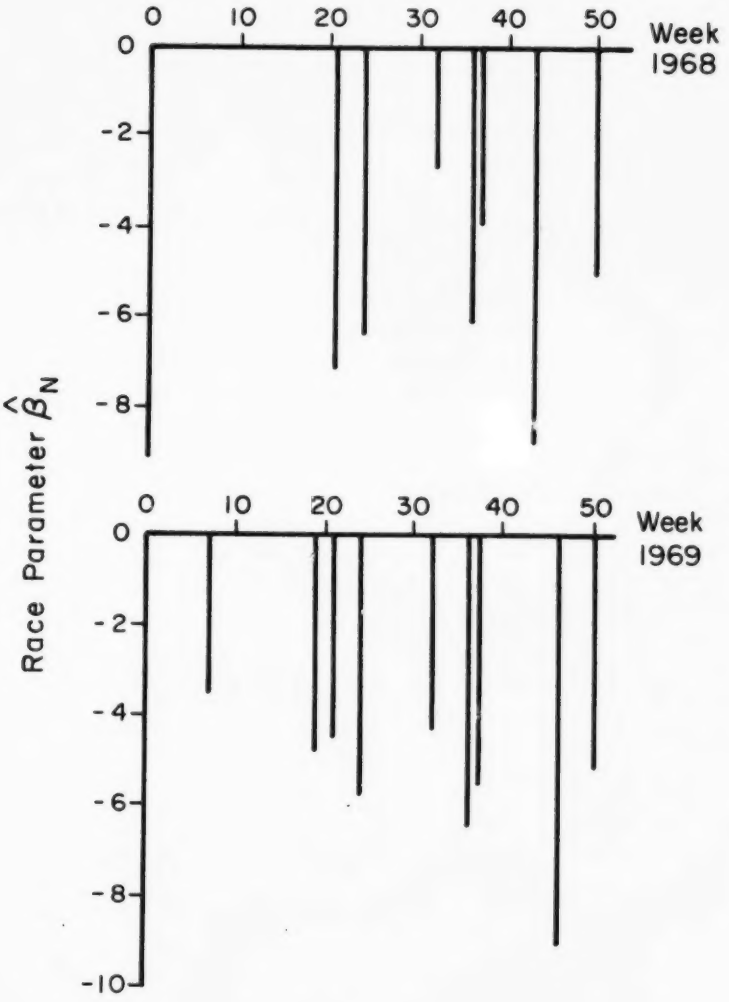

FIGURE 4: RACE SENSITIVITY OF SOLID WASTE OUTPUT

The elasticity of waste yields with respect to the fraction of nonwhites becomes the higher the more nonwhites live in a ward because the linear correlation equation dominates the other forms. The relationship between waste output and fraction of nonwhites is, in the linear setup, a negative one: The higher the fraction of nonwhites, the lower is the volume of solid wastes. This may be due to poor collection in nonwhite wards. Whatever the reason may be, there is a marked seasonal pattern in the negative impact of race on the yield of solid wastes, which repeats itself the next year. This pattern is shown in Figure 4 for the numerical values of the parameter β_N in Equation (2). The largest impact is in Weeks 43, 1968, and 46, 1969, which were weeks when the income elasticity is also highest. In Week 32 of both years, where the income elasticity is low, the negative impact of race is also low; the same is true for the winter Week 50 of both years and 7, 1969. This suggests that there is a common cause behind both patterns. We turn, therefore, to regressions in which both variables, income, Y_i, and race, N_i, are jointly used as explanatory variables.

Income and Race

When both, income and fraction of nonwhites are used to explain the solid waste yield in the ith ward, the household waste variable D_i is better than the per capita variable, C_i, judged by the R^2 criterion. The linear equation is generally better than the logarithmic equation, and the impact of race is now positive, not negative.* This suggests that the fraction of nonwhites, taken alone, picks up much of the income difference between white and nonwhite wards.

Figure 5 depicts values from the linear equation for wastes per household D_i and shows the estimated income parameters $\hat{\beta}_Y$, the race parameters $\hat{\beta}_N$, and the corresponding R^2 coefficients. Again, a seasonal pattern becomes visible. The income sensitivity $\hat{\beta}_Y$ is very low in winter. It is no longer as markedly below the average in the two August weeks (Nos. 32) as it was when income was taken alone. The reason becomes clear when the race impact for these two weeks is taken into account. In midsummer (Week 32) the fraction of nonwhites is a

*The two exceptions are Weeks 43 and 50, 1968.

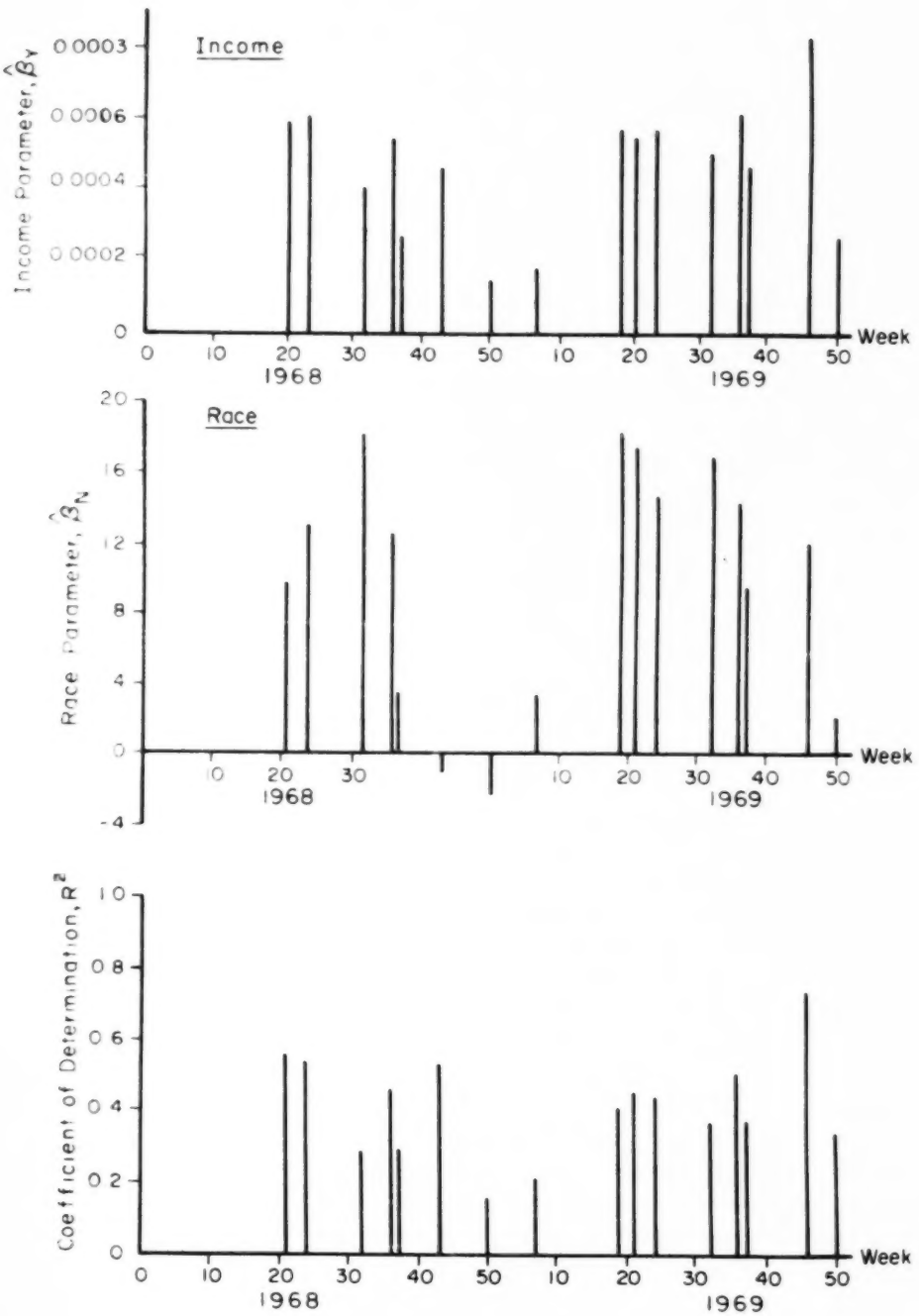

FIGURE 5 . RACE AND INCOME SENSITIVITY OF REFUSE COLLECTION BASED ON LINEAR PER HOUSEHOLD FUNCTION

very important factor determining the quantity of solid wastes, while income is slightly less important than on the average. In midwinter, on the other hand, race is irrelevant (negatively related) to the quantity of solid wastes, and income does not have much influence either. During the rest of the year, income as well as race are both essential for the determination of the demand for waste collection services. The contribution of both variables is positive. Since the linear function outperforms other forms, indications are that the income elasticity of solid waste output is higher the more a family earns; and that the elasticity with respect to the fraction of nonwhites increases with the concentration of nonwhites in the neighborhood.

INTERPRETATION OF THE RESULTS

One possible interpretation of these results is that solid waste can be divided into two components which depend on several factors. One component is the "basic" waste that accrues throughout the year at a constant rate, and is independent of income and race. The other component "excess" waste, is highly fluctuative. The quantity of "excess" waste varies with the season. In midwinter, the quantity is negligible. It increases in spring, reaches a peak in early July, and levels off in fall. It is very sensitive toward income and race, except in midsummer, when it stems from different consumption activities that are independent of income and more popular with nonwhite than with white families.

In summary, household refuse collected by the City of Chicago shows a clear seasonal pattern. Not only does the quantity of solid wastes vary seasonally, but also its determinants. In winter, there is less waste than in summer, and the smaller quantity appears to be of a different character. Winter waste is less sensitive toward income and race than normal. Within these limitations, a major conclusion can be stated regarding the influence of income and the fraction of nonwhites on the demand for household refuse collection service. The conclusion is that the demand is a positive function of the income level and the fraction of nonwhites using the service provided by the City of Chicago.

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